EXHIBIT 1

Curriculum Vitae for

Charles G. Boncelet Jr.

1 Employment History:

University of Delaware Currently *Professor in the Departments of Electrical & Computer Engineering (ECE) and Computer & Information Sciences (CIS).* First employed in 1984, promoted to Associate in 1989 and to Full Professor in 1995. Associate Chair of the ECE Dept. 2004–Present, Interim Chair of the EE Dept., 1/94–8/94, Assistant Chair EE Dept., 1/90–6/90. *Visiting Associate Professor of Electrical Engineering and Computer Science*, University of Michigan, 8/92–12/92. *Visiting Professor*, Signal Processing Laboratory, Tampere University of Technology, Tampere Finland, 7/99–12/99. *Honorary Visiting Professor*, Australian Defence Force Academy, Canberra Australia, 1/00-7/00.

President of the University of Delaware Faculty Senate, 2004–05. Member of the University of Delaware Faculty Senate, 1991–95, 2001-04.

Chair of the following committees: ECE Undergraduate Committee, 2002-Present. ECE Curriculum Committee, 2000-2001; ECE Faculty Search Committee, 1999; Faculty Senate Committee on Student and Faculty Honors, 1989–90; Faculty Senate Committe on Committees, 1994–95;

Member of the following committees: College of Engineering ABET Committee, 2000–Present. College of Engineering First Year Committee, 2004–Present. College of Engineering Promotion and Tenure Committee, 1997-99; Computer and Information Sciences Chair Search Committee, 1998–99; University Graduate Student Competitive Fellowship Committee, 1999; College Support Services Committee, 1996; University TA Development Advisory Committee, 1996-97; College of Engineering Educational Ethics Committee, 1986–88; EE graduate committee, 1985–94.

Taught graduate courses in multimedia, signals and systems, information theory, and communications. Taught undergraduate courses in networking, multimedia, random signals and noise, digital circuit theory, analog circuit

theory, and digital signal processing.

Bell Telephone Laboratories: *Member of Technical Staff,* 1980–81. Studied interference in satellite communications.

2 Education

Ph.D., Electrical Engineering and Computer Science Princeton University, 1984. Advisor: Professor Bradley Dickinson. Dissertation title: *Approaches and Algorithms for Robust Signal Processing.*

M.S., Electrical Engineering and Computer Science Princeton University, 1981. Participated in the Bell Labs One Year On Campus (OYOC) program.

B.S., Applied and Engineering Physics Cornell University, 1980. Graduated with distinction (3.9 average). Received McMullen-Dean's scholarship. Rowed on freshman lightweight crew.

3 Professional Activities and Research Summary

Professional Activities: Conference Board, 2005 ICASSP Conference; Publications Chair, 2001 NSIP Conference; General Conference Chair, ARL/ATIRP Annual Conference, Jan. 1998; Member, IEEE Signal Processing Society Publications Board, 1997-2000; CD-ROM Publications Chair, *1995 IEEE International Conference on Image Processing,* Washington DC, Oct. 1995; Conference Co-Chair, *1991 and 1992 SPIE Conferences on Nonlinear Image Processing,* San Jose, CA; Consultant: Princeton University, 1987, 1990, Alcoa Corporation, 1991; Member, *NSF Panel on Instrumentation, Sensing, and Measurement*, 1987.

Reviewer for many journals and textbooks, including the IEEE Transactions on Signal Processing, Information Theory, Image Processing, Automatic Control, and Signal Processing Letters.

Member of IEEE, SIAM, the Delaware Academy of Science, Eta Kappa Nu, and Tau Beta Pi.

Research Summary: Current Interests include nonlinear filtering, image processing, computer networking, data compression, multimedia, and digital watermarking and steganography.

Research highlights include the following: several techniques for image steganography and tamperproofing, block arithmetic coding (BAC) for entropy coding, new bilevel image compression methods, quadtree methods for lossless and lossy image compression, several families of nonlinear filters including the Ll-filters and the LUM filters, fast algorithms for doing order statistic computations, a robust version of the Kalman filter, and combinatorial algorithms for robust estimation.

4 Graduate Students Supervised

Ph.D. Degrees:

- L. Marvel, *Image Steganography for Hidden Communication*, 1999.
- M. Reavy, *Topics in block arithmetic coding*, 1998.
- J. Shin, *The UDel switch: an approach to very large fast packet switches*, 1997.
- J. Wunderlich, *Optimal kinematic design of redundant and hyper-redundant manipulators for constrained workspaces*, 1996.
- C. Myrie, *A high performance digital multi-window quadtree video compression encoding system*, 1994.
- A. Jackson, *Periodic multicast scheduling in reservation-based TDMA networks*, 1993.

- R. Hardie, *Nonlinear filters for signal restoration and enhancement,* 1992.
- R. Hakami, *High performance systems for robust image enhancement and restoration,* 1991.
- F. Palmieri, *Nonlinear filtering for robust signal processing,* 1987.

M.S. Degrees:

- N. Belal, *Simple, High Performance Lossless Image Compression*, 2005.
- V. Dasari, *Detection of Denial of Service Attacks in Wireless Networks,* 2005.
- D. Ulmer, *Broadcast Effectiveness Enhancement for Vehicle Safety Communications Using IEEE 802.11A*, 2004.
- K. Bao, *A New Algorithm for Still Image Compression,* 1999.
- H. Taylor, *Hyperspectral image compression for scientific applications,* 1998.
- J. Zhou, *DCT image compression with subband coding*, 1998.
- C. Hong, *DCT image compression with adaptive block-size segmentation,* 1996.
- L. Freed, *A comparison of block arithmetic coding with several other data compression techniques*, 1995.
- L. Marvel, *Robust source coding of images with predictive trellis coded quantization*, 1995.
- J. Donovan, *An interpolation scheme for image reconstruction with the MWQT algorithm* , 1995.
- M. Olds, *An interframe video modification of the JPEG image compression algorithm using differencing,* 1994.
- T. Hall, *A comparison of the JPEG standard for image compression with subband coding and the multi-window quadtree algorithm,* 1991.

- J. Holland, *Ocean thermal feature recognition, discrimination, and tracking using infrared satellite imagery,* 1991.
- B. Chang, *Applications for arithmetic coding: data compression, channel coding and error control,* 1991.
- S. Flynn, *Fast image decompression and display using the multi-window quadtree algorithm,* 1991
- G. Soemarwoto, *Robust Kalman filtering,* 1991.
- C. Buzzard, *Using a multi-window quadtree for image compression and decompression,* 1990.
- J. Cobbs, *Image compression using arithmetic coding techniques,* 1988.
- D. Hohman, *Robust smoothers applied to image filtering and enhancement,* 1987.
- S. Weber, *Ultrasonic nondestructive evaluation based upon complete waveform databases,* 1987.

5 Research Grants

- $165,000, *Steganalysis of Image and Video Steganography*, NSF, Jan 2005–Dec. 2006.
- $120,000, "Towards a Theory of Steganalysis for Images and Multimedia", NGA, Aug. 2005–July 2006.
- $4 million, Army Research Laboratory CTA on Telecommunications and Networking, C. G. Boncelet Jr.and 9 other UD faculty. Boncelet leads UD's participation in larger consortium. 2001-2006.
- $3.5 million, Army Research Laboratory Consortium on Telecommunications and Information Distribution, C. G. Boncelet Jr.and 8 other UD faculty. U. of D. is part of a large consortium with the consortium sharing $46 million. Boncelet is in charge of the U.D. effort. Jan. 1996–2000.
- $15,000, Delmarva Power, in support of research in telecommunications and the electric utilities, 1995.

- $66,750, NSF-CISE Research Instrumentation, G. Arce *et al*, March 1994–July 1995.
- $848,861, *Performance and policy dimensions in internet routing,* D. Mills and C. G. Boncelet Jr., Darpa/Nasa Ames, Feb. 1, 1990–Aug. 31, 1994.
- $56,862, *Visual communications over networks,* C. G. Boncelet Jr.and G. Arce, DuPont Corporation and the State of Delaware Research Partnership, Dec. 1, 1989–May 31, 1991.
- $25,000, *Research into routing in packet switched networks with arbitrary topologies,* C. G. Boncelet Jr., Bellcore, June 1, 1989–May 31, 1990.
- $26,000, *Noiseless data compression with applications in digital radiography,* C. G. Boncelet Jr., DuPont Corporation, Sept. 1, 1987–Dec. 31, 1991.
- $14,000, *A statistical and computational study of a new robust smoother,* C. G. Boncelet Jr., UDRF, Jan. 15, 1985–June 30, 1986.
- $170,000, *A Computer Vision and Image Processing Laboratory,* I. Abdou, G. Arce, and C. G. Boncelet Jr.Unidel Foundation, 1985.

6 Patents

- "Spread Spectrum Image Steganography," C. G. Boncelet Jr., L. M. Marvel, and C. T. Retter, U. S. Patent #6557103.
- "Watermarking Methods for Digital Images and Videos," X. Xia, C. G. Boncelet Jr., and G. Arce, U. S. Patent #6556689.

7 Publications

Refereed Journal Publications:

1. "On the Use of Context Weighting in Lossless Bilevel Image Compression," S. Xiao and C. G. Boncelet Jr., *IEEE Trans. on Image Processing,* 2006.

2. "The CRC-NTMAC for Noisy Message Authentication," Yu Liu and C. G. Boncelet Jr., submitted to *IEEE Trans. on Information Forensics and Security*, 2006.

3. "The NTMAC for Authentication of Noisy Messages," C. G. Boncelet Jr., *IEEE Trans. on Information Forensics and Security*, March 2006.

4. "Spread Spectrum Message Authentication," S. Xiao, D. Carman, and C. G. Boncelet Jr., submitted to *IEEE Trans. on Communications*, 2005.

5. "A New Message Authentication Approach with Less Overhead and Greater Reliability", D. Carman and C. G. Boncelet Jr., *Advanced Security Research Journal*, McAfee Security, vol. VI, no. 1, Spring 2004.

6. "An Algorithm for Compression of Bi-level Images," M. D. Reavy and C. G. Boncelet Jr., *IEEE Trans. on Image Processing*, May 2001.

7. "Extending the BACIC algorithm for robust transmission over a noisy channel," M. D. Reavy and C. G. Boncelet Jr., *IEEE Trans. on Image Processing*, Vol. 9, No. 12, December 2000.

8. "Robust source coding of images for very noisy channels," L. M. Marvel, A. Khayrallah, and C. G. Boncelet Jr., *IEEE Trans. on Signal Processing*, April 1999.

9. "Spread Spectrum Image Steganography", L. M. Marvel, C. G. Boncelet Jr., and C. T. Retter, *IEEE Transactions on Image Processing*, August 1999

10. "A Technique for Hiding Information in DCT Compressed Images and Videos," C. G. Boncelet Jr.and L. M. Marvel, submitted to the *IEEE Transactions on Image Processing*, July 1999.

11. "Tamper Detection Schemes for Compressed Images and Noisy Channels," L. M. Marvel, G. W. Hartwig, C. G. Boncelet Jr., submitted to the *IEEE Transactions on Multimedia*, September 1999.

12. "Wavelet Transform Based Watermark for Digital Images," X. Xia, C. G. Boncelet Jr., and G. A. Arce, *Optics Express*, vol 3, no. 12, December 1998.

13. "Capacity of the Steganographic Channel," L. M. Marveland C. G. Boncelet Jr., submitted to the *IEEE Transactions on Communications*, May 1998.

14. "An Efficient DCT Based Embedded Image Coder," J. Zhou and C. G. Boncelet Jr., submitted to *IEEE Trans. on Image Processing,* March 1998.

15. "Geometric modeling of redundant manipulator kinematics in constrained workspaces using a local-optimization path planning technique," J. T. Wunderlich and C. G. Boncelet Jr., submitted to *IEEE Trans. on Robotics and Automation.*

16. "Gradient based edge detection using nonlinear edge enhancing prefilters," R. Hardie and C. G. Boncelet Jr., *IEEE Trans. on Image Processing,* Nov. 1995.

17. "A new VLSI architecture suitable for multi-dimensional order statistics filtering," R. Hakami, P. J. Warter, and C. G. Boncelet Jr., *IEEE Trans. on Signal Proc.*, April 1994.

18. "Block arithmetic coding for source compression," C. G. Boncelet Jr., *IEEE Trans. on Information Theory,* Sept. 1993.

19. "LUM filters: A class of rank-order-based filters for smoothing and sharpening," R. Hardie and C. G. Boncelet Jr., *IEEE Trans. Signal Proc.,* vol. 41, no. 3, pp. 1061–1076, March 1993.

20. "A labeling algorithm for just-in-time scheduling in TDMA networks," C. G. Boncelet Jr. and D. Mills, *Computer Communication Review,* vol. 22, no. 4, pp. 170–175, Oct. 1992.

21. "Order statistic distributions with multiple windows," C. G. Boncelet Jr., *IEEE Trans. on Information Theory,* vol. 37, no. 2, March 1991.

22. "Frequency analysis and synthesis of a class of nonlinear filters," F. Palmieri and C. G. Boncelet Jr., *IEEE Trans. on Acoust., Speech, and Signal Proc.,* vol. 38, no. 8, pp. 1363–1372, August 1990.

23. "Ll-filters—A new class of order statistic filters," F. Palmieri and C. G. Boncelet Jr., *IEEE Trans. on Acoust., Speech, and Signal Proc.,* vol. 37, no. 5, pp. 691–701, May 1989.

24. "Algorithms to compute order statistic distributions," C. G. Boncelet Jr., *SIAM J. Sci. Stat. Comput.,* vol. 8, no. 5, September 1987.

25. "An extension to the SRIF Kalman filter," C. G. Boncelet Jr. and B. W. Dickinson, *IEEE Trans. on Automatic Control,* February 1987.

26. "A rearranged DFT algorithm requiring $N^2/6$ multiplications," C. G. Boncelet Jr., *IEEE Trans. on Acoust., Speech, and Signal Proc.,* December 1986.

27. "A variant of Huber robust regression," C. G. Boncelet Jr. and B. W. Dickinson, *SIAM J. Sci. Stat. Comput.,* vol. 5, no. 3, pp. 720-734, September 1984.

Book Chapters

1. "Binary Image Compression", C. G. Boncelet, *Document and Image Compression*, M. Barni, Ed., CRC Press, 2006.

2. "Image Noise Models," C. G. Boncelet, *Handbook of Image and Video Processing,* A. Bovik, Ed., Academic Press, 2005.

3. "Image Noise Models," C. G. Boncelet, *Handbook of Image and Video Processing,* A. Bovik, Ed., Academic Press, 2000.

Technical Conference Publications and Presentations:

1. "The BCH-NTMAC for Noisy Message Authentication," Y. Liu and C. G. Boncelet Jr., *Proceedings of the 2006 CISS*, Mar. 2006.

2. "Efficient Noise-Tolerant Message Authentication Codes Using Direct Sequence Spread Spectrum Technique," S. Xiao and C. G. Boncelet Jr., *Proceedings of the 2006 CISS*, Mar. 2006.

3. "Compression-Based Steganalysis of LSB Embedded Images," C. G. Boncelet Jr., L. M. Marvel, and A. Raglin, *Proceedings of Electronic Imaging'06*, Jan 2006.

4. "Efficient Message Authentication for Spread Spectrum Wireless Communications," S. Xiao, D. Carman, and C. G. Boncelet Jr., *Proceedings of MILCOM 2005*, Oct. 2005.

5. "The CRC-NTMAC for Noisy Message Authentication," Y. Liu and C. G. Boncelet Jr., *Proceedings of MILCOM 2005*, Oct. 2005.

6. "Image Authentication and Tamperproofing for Noisy Channels," C. G. Boncelet Jr., *Proceedings of ICIP 2005*, Sept. 2005.

7. "An Efficient Message Authentication Scheme Using Direct Sequence Spread Spectrum," S. Xiao and C. G. Boncelet Jr., *Proceedings of the 2005 CISS*, Mar. 2005.

8. "Parity Noise Tolerant Message Authentication Code (PNTMAC) for Noisy Message Authentication," Y. Liu and C. G. Boncelet Jr., *Proceedings of the 2005 CISS*, Mar. 2005.

9. "A Context-Weighting Algorithm Achieving Model Adaptability in Lossless Bi-Level Image Compression," S. Xiao and C. G. Boncelet Jr., *Proceedings of ICIP 2003*, Sept. 2003.

10. "Simple, High Performance Lossless Image Compression," C. G. Boncelet Jr., *Proc. IEEE ICIP Conference,* Thessaloniki, Greece, October 2001.

11. "Authentication for Low Power Systems," L. M. Marvel and C. G. Boncelet Jr., *Proceedings of MILCOM 2001*, Oct. 2001.

12. "Variable to Fixed Entropy Coders: Why and How? (And their application to H.263)," C. G. Boncelet Jr., *Proceedings of EUSIPCO 2000,* Tampere Finland, September 2000.

13. "Using Permutations to Hide Information," H. Huttunen and C. G. Boncelet Jr., *Proceedings of EUSIPCO 2000,* Tampere Finland, September 2000.

14. "Compression Compatible Fragile and Semi-Fragile Tamper Detection," L.M. Marvel, G. Hartwig, C. G. Boncelet Jr., *SPIE International Conf. on Security and Watermarking of Multimedia Contents II,* vol. 3971, No. 12, EI '00, San Jose, USA, Jan 2000.

15. "Applications of Information Hiding," G. A. Arce, C. G. Boncelet Jr., R. F. Graveman, L. M. Marvel, *ARL/ATIRP Federated Laboratory, 3nd Annual Symposium,* College Park, MD, Feb 1999.

16. "Recent Results in Image Steganography," L. M. Marvel and C. G. Boncelet Jr., *ARL/ATIRP Federated Laboratory, 3nd Annual Symposium,* College Park, MD, Feb 1999.

17. "Recent Work in DCT Image Compression," C. G. Boncelet Jr., *AMCOM Workshop on Data Compression Processing Techniques for Missile Guidance Data Links*, Huntsville AL, Dec. 1998.

18. "On Techniques for Hiding Information in Images and Videos," L. M. Marvel and C. G. Boncelet Jr., *AMCOM Workshop on Data Compression Processing Techniques for Missile Guidance Data Links*, Huntsville AL, Dec. 1998.

19. "Hiding Information in Images," L.M. Marvel, C.G. Boncelet, Jr., and C.T. Retter, *IEEE Conference on Military Communications (MILCOM'98)*, Boston, MA, Oct 1998

20. "Hiding Information in Images," L.M. Marvel, C.G. Boncelet, Jr., and C.T. Retter, *1998 IEEE International Conference on Image Processing*, Chicago, IL, Oct 1998.

21. "Reliable Blind Information Hiding for Images," L.M. Marvel, C.G. Boncelet, Jr., and C.T. Retter, *2nd International Workshop on Information Hiding*, Portland, OR, April 1998

22. "On Universal Estimation," C. G. Boncelet Jr., *Proceedings of the Conference on Information Science and Systems*, Princeton NJ, March 1998.

23. "Spread Spectrum Image Steganography", L.M. Marvel, C. G. Boncelet Jr., and C.T. Retter, *ARL/ATIRP Federated Laboratory, 2nd Annual Symposium*, College Park, MD, Feb 1998.

24. "A multiresolution watermark for digital images," X. Xia, C. G. Boncelet Jr., and G. Arce, *Proceedings of the 1997 IEEE International Conference on Image Processing*, Santa Barbara CA, 1997.

25. "On the use of the Huber estimator in nonlinear image processing," C. G. Boncelet Jr., *Proceedings of the 1997 IEEE/EURASIP Workshop on Nonlinear Signal and Image Processing*, 1997.

26. "A New Algorithm For Bi-level Image Compression," M. D. Reavy and C. G. Boncelet Jr., *Proceedings of the Conference on Information Science and Signals, 1997.* Baltimore MD, March 1997.

27. "BACIC: A New Method For Lossless Bi-level and Grayscale Image Compression," M. D. Reavy and C. G. Boncelet, *Proceedings of the 1997 International Conference on Image Processing*, Santa Barbara CA, 1997.

28. "Look-ahead predictive trellis coded quantization with nonlinear filters for image transmission over tactical channels", L.M. Marvel and C.G. Boncelet, Jr., *Proceedings of the 1997 SPIE Photonics West - Electronic Imaging Science and Technology*, San Jose, CA, February 1997.

29. "A new method for transmitting binary and facsimile images," C. G. Boncelet Jr. and M. D. Reavy, *Proceedings of the Advanced Telecommunications/Information Distribution Program*, College Park MD, January 1997.

30. "Performance issues of tactical internet architectures," S. Chamberlain and C. G. Boncelet Jr., *Proceedings of the Advanced Telecommunications/Information Distribution Program*, College Park MD, January 1997.

31. "Block arithmetic coding and its application to the JBIG algorithm," M. D. Reavy and C. G. Boncelet Jr., *Proceedings of the 1996 ISITA Conference*, Vancouver Canada, Sept. 1996.

32. "Robust source coding for images over very noisy channels," L. M. Marvel, A. Khayrallah, and C. G. Boncelet Jr., *Proceedings of the 1996 IEEE International Conference on Image Processing,* Lausanne Switzerland, Sept. 1996.

33. "Robust source coding of images for tactical channels," L. M. Marvel and C. G. Boncelet Jr., *Proceedings of the 20th Army Science Conference*, Norfolk VA, June 1996.

34. "Local optimization of redundant manipulator kinematics within constrained workspaces," J. Wunderlich and C. G. Boncelet Jr., *Proceedings of the 1996 IEEE International Conference on Robotics and Automation*, April 1996.

35. "Moment solutions for the block arithmetic code", M. D. Reavy and C. G. Boncelet Jr., *Proceedings of the 1996 Conference on Information Sciences and Systems*, Princeton NJ, March 1996.

36. "Block arithmetic coding and error correcting coding," C. G. Boncelet Jr., *Proceedings of the 1994 IEEE International Symposium on Information Theory*, June 1994.

37. "On Multi-Access Schemes for High Speed Broadcast Channels With Erasures," C. G. Boncelet Jr., *Proceedings of the 1994 Conference on Information Science and Systems*, March 1994.

38. "Block arithmetic coding for Markov sources," C. G. Boncelet Jr., *Proceedings of the 1993 IEEE International Symposium on Information Theory*, January 1993.

39. "A labeling algorithm for just-in-time scheduling in TDMA networks," C. G. Boncelet Jr. and D. Mills, *Proceedings of the ACM SIGCOMM 92*, August 1992.

40. "Extensions to block arithmetic coding," C. G. Boncelet Jr., *Proceedings of the 1992 Conference on Information Science and Systems*, March 1992.

41. "VLSI architectures for recursive and multiple-window order statistic filtering," R. Hakami, P. Warter, C. G. Boncelet Jr., and D. Nassimi, *Proceedings of the 6th International Parallel Processing Symposium*, March 1992.

42. "Generalized and adaptive LUM smoothers for image filtering," R. Hakami and C. G. Boncelet Jr., *Proceedings of the 1992 SPIE Conference on Nonlinear Image Processing III*, February 1992.

43. "The application of nonlinear filters to edge detection," R. Hardie and C. G. Boncelet Jr., *Proceedings of the 1992 SPIE Conference on Nonlinear Image Processing III*, February 1992.

44. "A new class of order statistic based filters for smoothing and sharpening", R. Hardie and C. G. Boncelet Jr., *Proceedings of the Twenty-Fifth Annual Conference on Information Sciences and Systems*, March 1991.

45. "A class of recursive VLSI architectures for order statistic filtering", R. Hakami, P. Warter, and C. G. Boncelet Jr., *Proceedings of the Twenty-Fifth Annual Conference on Information Sciences and Systems*, March 1991.

46. "LUM filters for smoothing and sharpening," C. G. Boncelet Jr., R. Hardie, R. Hakami, and G. Arce, *Proceedings of the 1991 SPIE Symposium on Electronic Imaging Science and Technology*, February 1991.

47. "Evaluation of the JPEG lossy sequential compression algorithm on 12 bit medical images," T. H. Hall, A. R. Moser, and C. G. Boncelet Jr., *Proceedings of the 1990 SPIE Symposium on Electronic Imaging*, November 1990.

48. "The MWQT image compression algorithm," C. G. Boncelet Jr., *Proceedings of the 1990 Conference on Information Sciences and Systems,* Princeton NJ, March 1990.

49. "A simple routing protocol for packet switched networks with arbitrary topologies," A. Jackson and C. G. Boncelet Jr., *Proceedings of the 1990 Conference on Information Sciences and Systems,* Princeton NJ, March 1990.

50. "Video coding with the MWQT algorithm," C. G. Boncelet Jr., *Proceedings of the 1990 Picture Coding Symposium,* Cambridge MA, March 1990.

51. "Some uses for order statistic filtering in image compression," C. G. Boncelet Jr., *Proceedings of the 1990 SPIE Symposium on Electronic Imaging,* February 1990.

52. "Image filtering derived from a model of quantum limited detection," P. Warter and C. G. Boncelet Jr., *Proceedings of the 1990 SPIE Symposium on Electronic Imaging,* February 1990.

53. "Some theory of multistage order statistic filters," C. G. Boncelet Jr., *Proceedings of the 1989 Midwest Symposium on Circuits and Systems,* Champaign, Ill., August 1989.

54. "Compression of halftone images with arithmetic coding," C. G. Boncelet Jr. and J. Cobbs, *Proceedings of the SPSE's 42nd Annual Conference,* Boston MA, May 1989.

55. "MWQT: A new tree algorithm for image compression," C. G. Boncelet Jr., *Proceedings of the 1989 Conference on Information Sciences and Systems,* Baltimore, MD, March 1989.

56. "Error free compression of medical X-ray images," C. G. Boncelet Jr., J. Cobbs, and A. Moser, *Proceedings of the 1988 SPIE Conference on Visual Communications and Image Processing III,* Cambridge MA, November 1988.

57. "Characterizing porosity of composite laminates through digitized ultrasonic waveform processing," S. Weber, R. Teti, R. Blake, and C. G. Boncelet Jr., *Proceedings of the Review of Progress in Quantitative NDE,* La Jolla CA, August 1988.

58. "Recursive algorithms and VLSI implementations for median filtering," C. G. Boncelet Jr., *Proceedings of the 1988 IEEE International Symposium on Circuits and Systems,* Espoo, Finland, June 1988, invited paper.

59. "A class of nonlinear adaptive filters," F. Palmieri and C. G. Boncelet Jr., *Proceedings of the 1988 ICASSP, Volume 3,* New York NY, April 1988.

60. "Novel tree based encodings for noiseless compression of images," C. G. Boncelet Jr., P. J. Warter, and T. A. Hall, *Proceedings of the Twenty–Second Conference on Information Sciences and Systems,* Princeton NJ, March 1988.

61. "Design of order statistics filters with given spectral behavior," F. Palmieri and C. G. Boncelet Jr., *Proceedings of the Twenty-First Annual Conference on Information Sciences and Systems,* Baltimore MD, March 1987.

62. "The efficient design of order statistic filters," C. G. Boncelet Jr., *Proceedings of the Twenty-Fourth Annual Allerton Conference,* Monticello IL, October 1986.

63. "Ll-filters," F. Palmieri and C. G. Boncelet Jr., *Proceedings of the Twenty-Fourth Annual Allerton Conference,* Monticello IL, October 1986.

64. "An expert system approach to full volume ultrasonic characterization of composite materials," S. Weber and C. G. Boncelet Jr., *1986 University-Industry Research Symposium,* Newark DE, September 1986.

65. "Image smoothing with robust estimators," C. G. Boncelet Jr., *Proceedings of the Twentieth Conference on Information Sciences and Systems,* Princeton NJ, March 1986.

66. "Optimal MSE linear combination of order statistics for restoration of Markov processes," F. Palmieri and C. G. Boncelet Jr., *Proceedings of the Twentieth Conference on Information Sciences and Systems,* Princeton NJ, March 1986.

67. "Robust data smoothing," C. G. Boncelet Jr., *Proceedings of the Nineteenth Annual Conference on Information Sciences and Systems,* Baltimore MD, March 1985.

68. "Robust recursive estimation in linear models," C. G. Boncelet Jr., *IEEE International Symposium on Information Theory,* IEEE Information Theory Society, Brighton, England, June 1985.

69. "An approach to robust Kalman filtering," C. G. Boncelet Jr. and B. W. Dickinson, *Proceedings on the 22nd IEEE Conference on Decision & Control,* vol. 1, IEEE Control Systems Society, San Antonio TX, pp. 304-305, December 1983.

Other Publications:

1. "Block arithmetic coding for source compression," C. G. Boncelet Jr., University of Delaware Department of Electrical Engineering Technical Report Number 91–8–1.
2. "A robust class of regression-based restoration algorithms suitable for parallel implementation", R. Hakami and C. G. Boncelet Jr., University of Delaware Department of Electrical Engineering Technical Report Number 91–7–1.
3. "A new VLSI architecture suitable for multi-dimensional order statistics filtering," R. Hakami, P. J. Warter, and C. G. Boncelet Jr., University of Delaware Department of Electrical Engineering Technical Report Number 91–7–2.
4. "Image enhancement software for the investigation of ultrasonic nondestructive evaluation data," M. G. Xakellis, K. V. Steiner, and C. G. Boncelet Jr., University of Delaware Center for Composite Materials Technical Report Number 91–44.
5. "Highball: a high speed, reserved access wide area network," D. Mills, C. G. Boncelet Jr., J. Elias, P. A. Schragger, and A. W. Jackson, University of Delaware Department of Electrical Engineering Technical Report Number 90–9–3.
6. "Design of order statistics I: L-filters," F. Palmieri and C. G. Boncelet Jr., University of Delaware Department of Electrical Engineering Technical Report Number 88–4–2.
7. "Design of order statistics II: Ll-filters," F. Palmieri and C. G. Boncelet Jr., University of Delaware Department of Electrical Engineering Technical Report Number 88–4–3.

8. "Bitwise tree-based algorithm for noiseless image compression," T. Hall and C. G. Boncelet Jr., University of Delaware Department of Electrical Engineering Technical Report Number 88–3–1.

9. "Order statistic distributions with multiple windows," C. G. Boncelet Jr., University of Delaware Department of Electrical Engineering Technical Report Number 87–12–2.

10. "Robust recursive estimation in linear models," C. G. Boncelet Jr., University of Delaware Department of Electrical Engineering Technical Report Number 87–12–1.

11. "Approaches and algorithms for robust signal processing," C. G. Boncelet Jr., Doctoral Dissertation from Princeton University, Dept. of EECS, Princeton NJ, 1984.

12. "A comparison between thermal noise and wideband digital interferers into FM color television signals," C. G. Boncelet Jr., Bell Telephone Laboratories Technical Memorandum No. 40370-002.

EXHIBIT 2

Reference Output Medium Metric RGB Color Space (ROMM RGB) White Paper

Eastman Kodak Company

Abstract

A new color space known as *Reference Output Medium Metric RGB* (*ROMM RGB*) is defined. This color space is intended to be used for manipulating images that exist in a *rendered image state*. This color space was chosen to provide a large enough color gamut to encompass most common output devices, and is defined in a way that is tightly linked to the ICC profile connection space (PCS). Examples of manipulations that might be applied in this color space include scene balance algorithms, manual color/density/contrast/ tone scale adjustments, red-eye correction, and dust/scratch removal. The color space is also appropriate for archiving and/or interchanging rendered images. 8-bit, 12-bit and 16-bit versions of this color space are defined.

I. Introduction

In digital imaging systems, most images exist in color spaces that are directly tied to the color of a desired output image. Examples of common color spaces that are used include scanner RGB, video RGB, and CMYK. However, these color spaces are *device-dependent* in the sense that the color values are associated with an actual perceived color only in the context of the characteristics of the device on which the image is displayed or scanned.

On the other hand, *device-independent color spaces* are designed to describe the color that is perceived by a human observer. These color spaces are generally based on the system developed by the Commission International de l'Eclairage (CIE). Examples of device-independent color spaces include XYZ tristimulus values, and CIELAB. It should be noted that the specification of a color value in a device-independent color space does not fully specify color appearance unless the viewing conditions are known (i.e., two patches with identical tristimulus values can have very different color appearance depending on the conditions under which they are viewed).

The fact that images exist in many device-dependent color spaces significantly complicates the development of software that uses and manipulates images. For example, an algorithm that works in one color space might not have the expected behavior in another color space. This has led many people to advocate the use of a standard color space for the storage and manipulation of digital images. Generally, these proposals have involved specifying some particular device-dependent color space to be a "standard." Examples of these color spaces include *SWOP CMYK* and *sRGB*.

One significant problem with specifying a particular device-dependent color space as the standard color space is that it will necessarily limit the color gamut and dynamic range of an image to that of the specific output device. For example, most color printers have very different color gamuts than CRT video displays. Therefore, using *sRGB* (which is basically a particular video CRT model) as a standard color space would necessarily involve clipping many colors that could be produced on the final output printer to the CRT gamut.

The International Color Consortium (ICC) has defined a Profile Connection Space (PCS) that comprises a device-independent color encoding that can be used to explicitly specify the color of an image with respect to a reference viewing environment. *Device profiles* can be used in a color management system to relate the device-dependent code values of some input images to the corresponding color values in the PCS, and from there to the device-dependent output color values appropriate for a specific output device. It could be argued that the PCS could serve as the standard color space we are looking for. However, it was never intended that the PCS be used to directly store or manipulate images. Rather, it was simply intended to be a color space where profiles could be joined to form complete color transforms. Neither the CIELAB nor the XYZ color encodings supported for the PCS are particularly well-suited for many common kinds of image manipulations.

It is therefore desirable to define a new standard large gamut color space that can be used for storing and/or manipulating color images. The color space should have a number of characteristics:

- It should be tightly coupled with the ICC Profile Connection Space.
- The transform to/from PCS should be relatively simple.
- The transform to/from video RGB should be relatively simple.
- The color gamut should be large enough to encompass most common output devices.
- The Color space should be appropriate for common image manipulations such as tone scale modifications, sharpening, etc.
- It should be easily extensible to different bit-precisions.

These criteria are all met by the *Reference Output Medium Metric RGB* (*ROMM RGB*) color space that will be described in the next section.

It should be noted that the *ROMM RGB* color space is designed to be used for *rendered output images*. This is evidenced by the fact that it is tightly coupled with the ICC PCS, which implicitly assumes the image is reflection-print-like, and is viewed in a reflection print viewing environment. Rendered output images should be distinguished from images that are intended to be an encoding of the colorimetry of an *original scene*. Color spaces, such as *ROMM RGB*, which are intended to be used for encoding rendered output images, would be inappropriate for use in encoding original scene images. Rather, a color space that can be directly related to the color of an original scene should be used. The *Kodak PhotoYCC* Color Interchange Space is one example of a color space of this type.

Many fundamental differences exist between images that are representations of an original scene, and images that are a representation of a rendered image. But the most significant difference is related to the dynamic range of an original scene relative to the dynamic range of a reflection print. A scene color space, such as the *Kodak PhotoYCC* Color Interchange Space, must be able to encode the larger dynamic range associated with scenes. Before converting an image in a scene color space to *ROMM RGB*, it is first necessary to determine the desired rendered output image colorimetry using some sort of tone/color reproduction aims. Note that this process necessarily involves discarding and/or compressing some of the information in the original scene encoding to fit the image within the smaller dynamic range of the rendered image encoding. Therefore, it will sometimes be desirable to apply some manipulations to the image before it is converted to a rendered image encoding such as *ROMM RGB*. For example, if an image needs to be darkened, there would be an advantage to performing this operation before converting the image to an output-rendered representation. This is because much of the

highlight information that could be used to darken the image will be lost during the conversion process.

Since one of the requirements for *ROMM RGB* is that it be tightly coupled to the ICC Profile Connection Space (PCS), it is appropriate to review the important features of this space. Color values in the PCS represent the CIE colorimetry of an image, which will produce the desired color appearance when viewed in a reference viewing environment. Eastman Kodak Company has defined a specific viewing environment that can be used to unambiguously define the PCS for the purposes of producing ICC profiles.[1-2] This reproduction viewing environment is defined to have the following characteristics:

- Luminance level is in the range of 160-640 cd/m^2.
- Viewing surround is average.
- There is 0.5-1.0% viewing flare.
- The adaptive white point is specified by the chromaticity values for D50: x = 0.3457 and y = 0.3585.
- The image color values are assumed to be encoded using flareless (or flare corrected) colorimetric measurements based on the CIE 1931 Standard Colorimetric Observer.

II. Definition of *ROMM RGB*

As mentioned above, several criteria were identified for selecting a desirable rendered image color manipulation space. These criteria are all satisfied by the *Reference Output Medium Metric RGB* (*ROMM RGB*) color space. It is defined by the color values associated with a hypothetical additive color device having the following characteristics:

- Reference primaries defined by the CIE chromaticities given in Table 1.
- Equal amounts of the reference primaries produce a neutral with the chromaticity of D50.
- The capability of producing a black with L* = 0.
- No cross-talk among the color channels (i.e., red output is affected only by red input, green output is affected only by green input, and blue output is affected only by blue input).

Table 1. Primaries/white point for Reference Output Medium.

Color	*x*	*y*
Red	0.7347	0.2653
Green	0.1596	0.8404
Blue	0.0366	0.0001
White	0.3457	0.3585

The primaries given in Table 1 were selected to provide a color gamut large enough to encompass most common output devices and to minimize the introduction of hue rotations during tone scale modifications.

Additionally, a quantization scheme must be specified to store the *ROMM RGB* values in an integer form. A simple gamma function nonlinearity incorporating a slope limit is defined for this purpose supporting 8-bit/channel, 12-bit/channel, and 16-bit/channel quantization schemes.

The conversion of the PCS XYZ tristimulus values to *ROMM RGB* values can be performed by a matrix operation, followed by a set of 1-D functions. This is equivalent to the operations associated with a basic CRT profile. This means that *ROMM RGB* can be used conveniently in a system employing ICC profiles using an appropriately designed monitor profile. The details of the conversion from XYZ to *ROMM RGB* will be described.

II.A. *ROMM RGB* Conversion Matrix

Given the defined primaries shown in Table 1, it can be shown that the following matrix can be derived to compute the linear *ROMM RGB* values from the PCS image tristimulus values:

$$\begin{bmatrix} R_{ROMM} \\ G_{ROMM} \\ B_{ROMM} \end{bmatrix} = \begin{bmatrix} 1.3460 & -0.2556 & -0.0511 \\ -0.5446 & 1.5082 & 0.0205 \\ 0.0000 & 0.0000 & 1.2123 \end{bmatrix} \begin{bmatrix} X_{PCS} \\ Y_{PCS} \\ Z_{PCS} \end{bmatrix}, \qquad (1)$$

where it is assumed that the PCS tristimulus values have been scaled so that the Y_{PCS} value for an idealized reflection paper media is 1.0. As required by the definition of the Reference Output Medium, image tristimulus values with the chromaticity of D50 map to equal *ROMM RGB* values. It can easily be shown that a neutral with a Y_{PCS} value of 1.0 maps to linear *ROMM RGB* values of 1.0. Consistent with the Kodak interpretation of the ICC profile connection space, these unity *ROMM RGB* values will therefore correspond to the white point of an idealized reflection paper media.

II.B. Nonlinear Encoding of *ROMM RGB*

The functional form of the *ROMM RGB* nonlinearity is a gamma function with a linear segment at the dark end of the intensity scale:

$$X'_{ROMM} = \begin{cases} 0; & X_{ROMM} < 0.0 \\ 16\, X_{ROMM}\, I_{\max}; & 0.0 \le X_{ROMM} < E_t \\ (X_{ROMM})^{1/1.8} I_{\max}; & E_t \le X_{ROMM} < 1.0 \\ I_{\max}; & X_{ROMM} \ge 1.0 \end{cases}, \qquad (2)$$

where X is either R, G, or B, I_{max} is the maximum integer value used for the nonlinear encoding, and

$$E_t = 16^{1.8/(1-1.8)} = 0.001953 \;. \qquad (3)$$

For the baseline 8-bit configuration, I_{max} is equal to 255. The linear segment of the nonlinearity is used to impose a slope limit so as to minimize reversibility problems because of the infinite slope of the gamma function at the zero point.

Table 2. Sample neutral patch encodings.

Relative Intensity	PCS *L**	*ROMM8 RGB*	*ROMM12 RGB*	*ROMM16 RGB*
0.00	0.00	0	0	0
0.001	0.90	4	66	1049
0.01	8.99	20	317	5074
0.10	37.84	71	1139	18236
0.18	49.50	98	1579	25278
0.35	65.75	142	2285	36574
0.50	76.07	174	2786	44590
0.75	89.39	217	3490	55855
1.00	100.00	255	4095	65535

A 12- and a 16-bit version of *ROMM RGB* are also defined. The only difference is that the value of I_{max} is set to 4095 or 65535, respectively. In cases in which it is necessary to identify a specific precision level, the notation *ROMM8 RGB*, *ROMM12 RGB* and *ROMM16 RGB* is used. Table 2 shows some sample encodings for a series of neutral patches of specified relative image intensity, where a relative image intensity of 1.0 corresponds to the white point of the PCS.

If *ROMM RGB* images are going to be stored in a file, then the image must be scaled to a bit-depth supported by the file format. In many cases this will limit the image bit-depth to the 8-bit or 16-bit encodings. In particular, for files that are to be read into Adobe Photoshop software, it is recommended that the 8-bit or 16-bit encoding options be used since Photoshop software supports only these bit-depths. If it is desired to store a *ROMM12 RGB* image in a file format that does not support 12-bit encoding, it is recommended that the code values first be scaled up by (65535/4095) to convert them to *ROMM16 RGB* values. Alternatively, they could be scaled down by (255/4095) to convert them to *ROM8 RGB* values and stored in an 8-bit file. However, the use of the 8-bit encoding will result in a loss of precision in the image data.

One potential use of the *ROMM RGB* color space is as a working color space for Adobe Photoshop software. However, it should be noted that Adobe Photoshop software currently limits the nonlinearity that can be used to define a valid working space to be a simple gamma function. However, both the Adobe Photoshop software implementation and the *Kodak Digital Science™* Color Matching Module (CMM) implementation automatically impose a *slope limit* of 16 at the dark end of the tone scale. Although a profile that explicitly incorporates the nonlinearity with the slope limit can not be used by Adobe Photoshop software, a profile using a simple gamma function nonlinearity produces the net effect of Eq. (2) when used by Adobe Photoshop software or the current version of the Kodak CMM. Therefore, to ensure Adobe Photoshop software compatibility, the *ROMM RGB* ICC profile created by Eastman Kodak Company uses a simple gamma function nonlinearity without the slope limit, rather than the form shown in Eq. (2). At some point in the future it may be possible to produce a new ICC profile that explicitly incorporates the slope limit if Adobe were to modify the Photoshop software to remove this artificial restriction. Although this would not have any effect on the results obtained using Adobe Photoshop software or the Kodak CMM, it would increase the likelihood that equivalent results would be obtained using different CMMs that may or may not include the same slope limiting feature.

III. Inverse of *ROMM RGB* Encoding

It is also necessary to define an inverse transformation to convert *ROMM RGB* values back to rendered image PCS values. This can be done by simply inverting the nonlinear function given in Eq. (2), and then applying the inverse of the matrix given in Eq. (1).

III.A. Inverse of *ROMM RGB* Nonlinear Encoding

The first step is to undo the nonlinear encoding of the *ROMM RGB* values. This will convert the signals back to linear *ROMM RGB* values.

$$X_{ROMM} = \begin{cases} \dfrac{X'_{ROMM}}{16\, I_{\max}}; & 0.0 \le X'_{ROMM} < 16\, E_t\, I_{\max} \\ \left(\dfrac{X'_{ROMM}}{I_{\max}}\right)^{1.8}; & 16\, E_t\, I_{\max} \le X'_{ROMM} \le I_{\max} \end{cases}, \tag{4}$$

where X'_{ROM} and X_{ROM} are the nonlinear and linear *ROMM RGB* values, respectively, and as before, *X* is either *R*, *G*, or *B*.

III.B. Conversion to Profile Connection Space (PCS)

To convert the *ROMM RGB* values to the corresponding D50 PCS tristimulus values, it is simply necessary to multiply by the inverse of the matrix given in Eq. (1)

$$\begin{bmatrix} X_{PCS} \\ Y_{PCS} \\ Z_{PCS} \end{bmatrix} = \begin{bmatrix} 0.7977 & 0.1352 & 0.0313 \\ 0.2880 & 0.7119 & 0.0001 \\ 0.0000 & 0.0000 & 0.8249 \end{bmatrix} \begin{bmatrix} R_{ROMM} \\ G_{ROMM} \\ B_{ROMM} \end{bmatrix}. \tag{5}$$

As expected, when this matrix is applied to linear *ROMM RGB* values that are equal, tristimulus values with the chromaticity of D50 are obtained.

IV. Conversion Between *ROMM RGB* and *sRGB*

In many cases, it will be necessary to convert *ROMM RGB* values to a video RGB representation for display on a CRT. This can be accomplished by combining the *ROMM RGB* to PCS transformation described in Section III with an appropriate PCS to video RGB transformation for the CRT. Consider the special case of a CRT that responds according to the *sRGB* specification. Because *sRGB* is defined using a D65 white point, and the PCS is defined using a D50 white point, the first step in the conversion of PCS values to *sRGB* values must be a D50-to-D65 chromatic adaptation:

$$\begin{bmatrix} X_{D65} \\ Y_{D65} \\ Z_{D65} \end{bmatrix} = \begin{bmatrix} 0.9845 & -0.0547 & 0.0678 \\ -0.0060 & 1.0048 & 0.0012 \\ 0.0000 & 0.0000 & 1.3200 \end{bmatrix} \begin{bmatrix} X_{D50} \\ Y_{D50} \\ Z_{D50} \end{bmatrix} = \overline{M}_{A,D50\to D65} \begin{bmatrix} X_{D50} \\ Y_{D50} \\ Z_{D50} \end{bmatrix}. \tag{6}$$

The *sRGB* color space is defined using the phosphor primaries associated with Rec. 709. It can be shown that the conversion from D65 tristimulus values to the linear RGB values associated with these primaries is given by the following inverse phosphor matrix:

$$\begin{bmatrix} R_S \\ G_S \\ B_S \end{bmatrix} = \begin{bmatrix} 3.2406 & -1.5372 & -0.4986 \\ -0.9689 & 1.8758 & 0.0415 \\ 0.0557 & -0.2040 & 1.0570 \end{bmatrix} \begin{bmatrix} X_{D65} \\ Y_{D65} \\ Z_{D65} \end{bmatrix} = \overline{M}_P^{-1} \begin{bmatrix} X_{D65} \\ Y_{D65} \\ Z_{D65} \end{bmatrix} . \tag{7}$$

Finally, the desired *sRGB* code values can be computed by applying the appropriate nonlinearity and integerizing:

$$X_S' = \begin{cases} 255(12.92X_S); & X_S \le 0.0031308 \\ 255(1.055X_S^{1/2.4} - 0.055); & X_S > 0.0031308 \end{cases} , \tag{8}$$

where X is either R, G, or B. It should be noted that despite the "2.4" in the exponent of Eq. (19), the *effective gamma* value associated with this nonlinearity is actually about 2.2 (where the effective gamma is determined from the slope of the straight-line portion of the curve when the nonlinearity is plotted with logarithmic axes). This is due to the effect of the offset term in the equation. The *sRGB* nonlinearity is designed to be representative of a typical CRT found on a PC.

Conversion from *ROMM RGB* values to the *sRGB* code values can therefore be accomplished by applying the inverse *ROMM RGB* nonlinearity given in Eq. (4), followed by the matrices given in Eqs. (5), (6) and (7), followed by the *sRGB* nonlinearity given in Eq. (8). The three sequential matrix operations can be combined by cascading the matrices together to form the following single matrix:

$$\begin{bmatrix} R_s \\ G_s \\ Bs \end{bmatrix} = \begin{bmatrix} 2.0564 & -0.7932 & -0.2632 \\ -0.2118 & 1.2490 & -0.0372 \\ -0.0152 & -0.1405 & 1.1556 \end{bmatrix} \begin{bmatrix} R_{ROMM} \\ G_{ROMM} \\ B_{ROMM} \end{bmatrix} . \tag{9}$$

Thus, the transformation from *ROMM RGB* to *sRGB* can be implemented with a simple LUT-MAT-LUT chain.

It should be noted that not all colors that can be encoded in *ROMM RGB* will be within the *sRGB* color gamut. As a result, it will be necessary to perform some sort of gamut mapping to clip all of the colors to the appropriate gamut. The simplest form of gamut mapping is just to clip all of the linear *sRGB* values to the range 0.0 to 1.0 before applying the nonlinearity of Eq. (8). However, this approach can result in noticeable hue shifts in certain cases. As a result, superior results can be obtained using more sophisticated gamut mapping strategies.

The conversion from *sRGB* back to *ROMM RGB* is simply an inverse of the steps that were just discussed. First, the inverse of the *sRGB* nonlinearity given in Eq. (8) is applied to determine the linear RGB_s values:

$$X_S = \begin{cases} \dfrac{\left(X_S^{'}/255\right)}{12.92}; & X_S^{'} \le 0.04045 \times 255 \\ \left(\dfrac{\left(X_S^{'}/255\right)+0.055}{1.055}\right); & X_S^{'} > 0.04045 \times 255 \end{cases} \quad . \tag{10}$$

Next, the inverse of the matrix in Eq. (9) is used to compute the linear RGB_{ROM} values,

$$\begin{bmatrix} R_{ROMM} \\ G_{ROMM} \\ B_{ROMM} \end{bmatrix} = \begin{bmatrix} 0.5230 & 0.3468 & 0.1303 \\ 0.0892 & 0.8627 & 0.0481 \\ 0.0177 & 0.1095 & 0.8729 \end{bmatrix} \begin{bmatrix} R_s \\ G_s \\ Bs \end{bmatrix} \quad . \tag{11}$$

Finally, the *ROMM RGB* nonlinearity given in Eq. (2) is applied to determine the *ROMM RGB* values.

As noted above, many colors that can be represented in *ROMM RGB* space are outside the gamut of *sRGB*. As a result, the process of mapping an image from *ROMM RGB* to *sRGB* and back again is not lossless in general. Therefore, it should be emphasized that, whenever possible, a video RGB color space should not be used as an intermediate color space during the process of manipulating a *ROMM RGB* image. Rather, the image manipulations should be applied to the *ROMM RGB* image directly, and the *ROMM RGB* to *sRGB* transformation should be used to provide an image for video preview purposes only.

On the other hand, if an original image is in a video RGB color space, it should be possible to convert the image to *ROMM RGB* for manipulation purposes, and then convert it back to the video RGB color space again with only minimal losses due to quantization effects. These quantization effects can be reduced to negligible levels by using the 12-bit or 16-bit versions of *ROMM RGB*. However, it should be noted that if the manipulation process creates any color values that are outside the video RGB gamut, these values will be clipped when the processed image is converted back to the original color space.

V. Conclusions

A new large gamut color space known as *Reference Output Medium Metric RGB* (*ROMM RGB*) has been defined. This color space is intended to be used for manipulating and/or interchanging images that exist in a *rendered image* state.[†]

† For more information please contact Kevin Spaulding (spaulding@kodak.com) or Chris Heinz (cheinz@ekbos.com).

References

1. S. Gregory, R. Poe and D. Walker, "Communicating color appearance with the ICC profile format," in *IS&T and SID's 2nd Color Imaging Conference: Color Science, Systems and Applications*, 170-174 (1994).
2. "Interpretation of the PCS," appendix to "Kodak ICC Profile for CMYK (SWOP) Input," ANSI CGATS/SC6 N 254, June 3, 1998.

Appendix A: Selection of *ROMM* Primaries

As discussed above, a number of criteria were examined during the definition of the *ROMM RGB* color spaces. This appendix will review some of these criteria that had a direct impact on the selection of the RGB primaries.

Color Gamut Considerations

One of the requirements for the *ROMM RGB* color space was that it have a large enough color gamut to encompass the colors produced by most common output devices, while simultaneously maintaining acceptable levels of quantization errors. The primaries for the *ROMM RGB* color space were chosen to enclose an experimentally determined gamut of real world surface colors, without making the gamut any larger than necessary in order to minimize quantization concerns. Figure A1 shows a CIE *x-y* chromaticity plot illustrating the *ROMM RGB* color gamut, which can be seen to encompass the gamut of real world surface colors. Also shown for comparison are the color gamuts for the sRGB and Photoshop Wide Gamut RGB color spaces. It can be seen that the sRGB gamut excludes large portions of the gamut of the real world surface colors. The Photoshop Wide Gamut RGB color gamut excludes only some small portions of the real world surface colors gamut in the saturated yellow and cyan regions. However, even though these regions are quite small in chromaticity space, the errors are larger in a more uniform color space, and actually correspond to some important colors, particularly in the yellows.

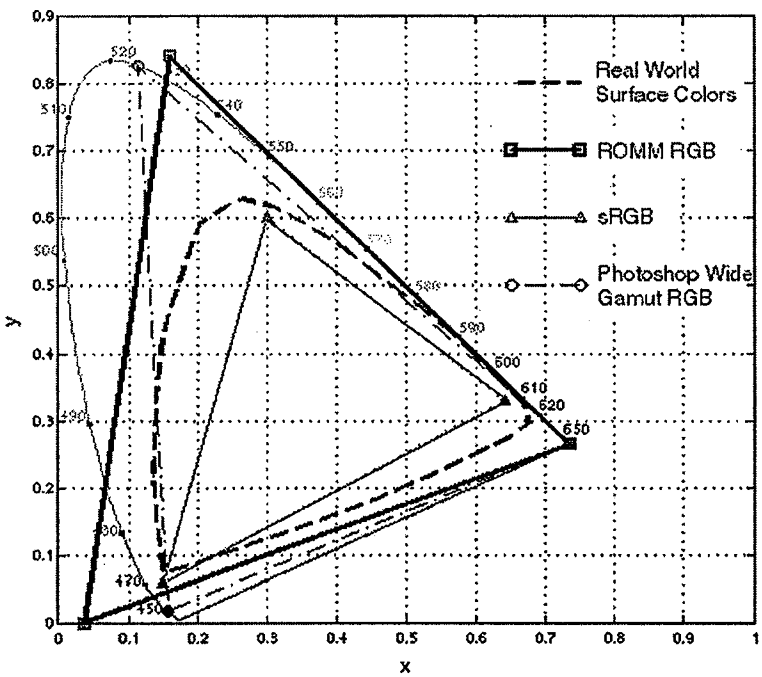

Fig. A1. Comparison of color gamuts.

Effect of Applying Tone Scale Manipulations on Shadow-Highlight Series

Another requirement for the *ROMM RGB* color space was that it be an appropriate color space for performing image manipulations. One of the most common types of manipulations is to adjust the image tone scale using one-dimensional shapers applied individually to the red, green, and blue channels of the image. Since the tone scale functions are typically nonlinear, hue shifts can occur when a highlight to shadow series of a given image chromaticity is mapped through the shaper. This is not a problem for neutrals and the effect is minimal for near neutral colors, but the effect can be significant for high chroma image colors. The reason for these hue shifts is that the nonlinear functions cause the ratios of the RGB intensities to change. Hue shifts are particularly problematic when they occur within a natural chroma gradient in an image. Such gradients tend to occur when rounded surfaces are lit by a moderately directional light source. In such situations chroma increases with distance from the specular highlight and then decreases again as the shadows deepen while maintaining a constant hue.

Hue shift effects were studied during the process of selecting the *ROMM RGB* primaries by examining a set of highlight-to-shadow series for eight color patches from the MacBeth color checker. These patches included red, yellow green, cyan, blue, magenta, light and dark flesh. Hue shifts in flesh tones and yellows, particularly in the direction of green, are considered to be the most objectionable. Figure A2 illustrates the hue shifts resulting from applying an S-shaped contrast-boosting tone scale using the *ROMM RGB* primaries. The graph shows a series of vectors indicating the a*-b* shift introduced by applying the tone scale function to each of the input colors. If the transformation were perfectly hue-preserving, the plot would show a series of spokes radiating out from the neutral point in the center. A similar plot for the Adobe Photoshop Wide Gamut RGB color space is shown in Fig. A3. Inspection of these figures shows that hue rotations for high-chroma yellows towards green are reduced in the *ROMM RGB* color space relative to the default Photoshop color space. Hue shifts for the blues, cyans, and flesh tones are also smaller for the *ROMM RGB* color space. With any set of primaries, hue shifts can never be completely eliminated for all colors. The objective when optimizing the location of the *ROMM RGB* primaries was to eliminate or minimize objectionable hue shifts for important memory colors.

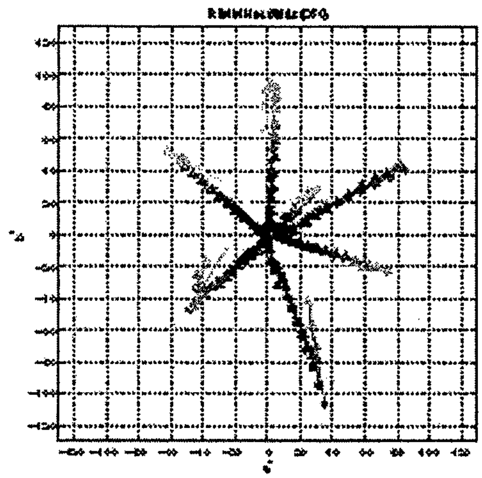

Fig. A2.: Hue shifts for the *ROMM RGB* primaries when rendered through a contrast boosting tone scale.

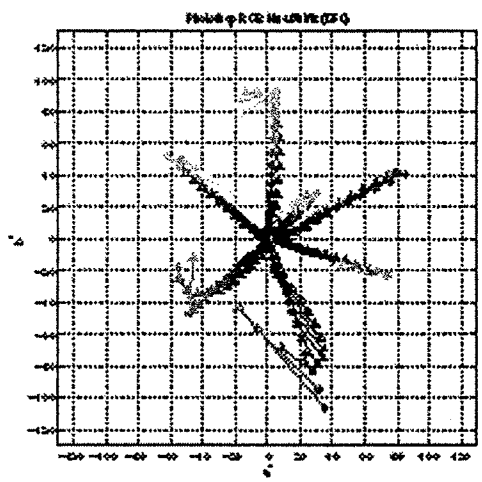

Fig. A3. Hue shifts for the default Adobe Photoshop Wide Gamut RGB primaries when rendered through a contrast-boosting tone scale.

Appendix B: Use of *ROMM RGB* as an *Adobe Photoshop* Software Working Space

Adobe Photoshop V5.0 software offers many new Color Management-related features designed to help professionals produce high-quality images more effectively. Two of the more significant new ICC features are ICC Profile Tagging and the decoupling of the monitor definition from RGB editing space (referred to as the "RGB Working Space"). One of the criteria for the definition of *ROMM RGB* was compatibility with usage as an Adobe Photoshop V5.0 software RGB Working Space. This appendix presents guidelines for how *ROMM RGB* can be used for this purpose in practice.

RGB Working Spaces

One of the objectives of the Adobe Photoshop V5.0 software CMS architecture is to allow multiple systems with different monitor spaces to view the same image accurately, without data conversion. To facilitate this, RGB color space editing is now independent from the workstation-specific (device dependent) monitor definition. This capability provides a color managed display image in video RGB while maintaining the ability to store the actual image in the larger color gamut workspace.

The RGB Working Space must be a simple, idealized color space that can be completely defined in terms of a single gamma, white point, and phosphor set. Kodak's provision for compatibility of the *ROMM RGB* with the Photoshop software's RGB Working Space requirements opens up a practical avenue for deployment of *ROMM RGB* as an intermediate processing and transfer space to facilitate ICC production methods. As a result, *ROMM RGB* serves as a convenient storage, edit, archive, and transfer color space for many professional imaging applications.

ICC Profile Tagging

ICC Profile Tagging is the linchpin that will hold together and help automate digital imaging processes in the future. In this scheme, TIFF and EPS images contain a profile that converts from the mode-specific color space to the ICC Profile Connection Space (PCS)—usually LAB. Specifically, *ROMM RGB* images can be tagged with a *ROMM RGB* Working Space profile, and then can be interpreted unambiguously in conforming processes downstream.

The combination of these two features—RGB Working Spaces and ICC Profile Tagging—make device-independent editing methods possible for the first time. Device-independent image editing is highly recommended for sites that plan to store and re-purpose digital image assets. Ultimately, it is anticipated that full-gamut editing will become "coin of the realm" and will continue to gradually displace (or reduce the need for) device-specific RGB and CMYK editing in all but specialty applications.

Creating an RGB Working Space

There are two ways to establish *ROMM RGB* as a working space:

(1) Load the Kodak-supplied *ROMM RGB* profile (if available)
(2) Enter the corresponding *ROMM RGB* parameters.

When a *ROMM RGB* ICC profile is available, it can be used to define the RGB Working Space in the following manner. First, select the *File>Color Settings>RGB Setup* Menu option:

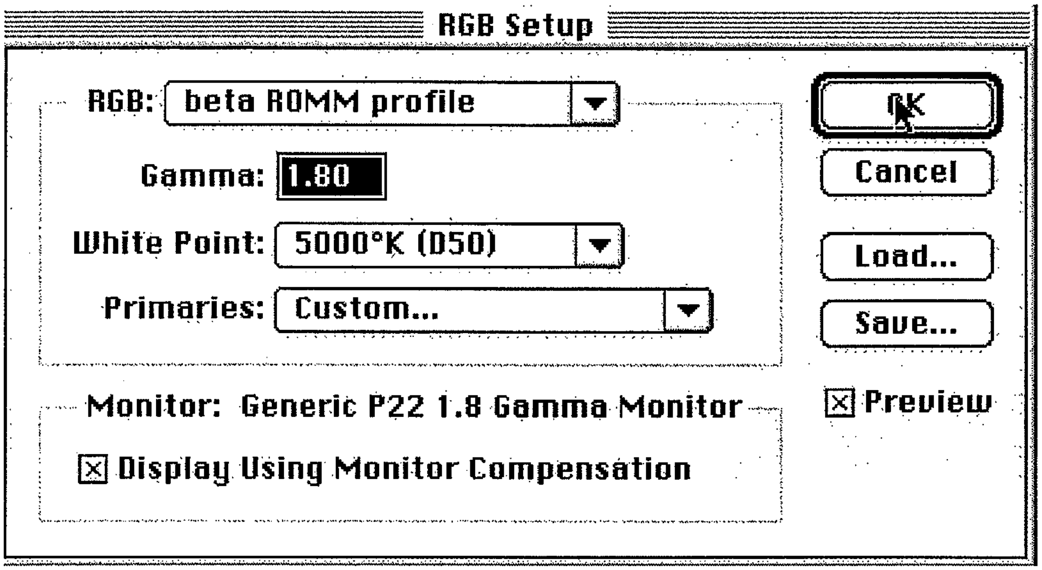

Fig. E1. Dialog box for *File>Color Settings>RGB Setup* Menu option.

To load the supplied *ROMM RGB* profile, simply select the "*Load...*" option. Navigate to the appropriate profiles directory, and select the *ROMM RGB* profile. The Photoshop software then reads the attributes necessary to activate the profile as a Working Space. The default directory for storing ICC profiles will be a function of the operating system:

- Macintosh OS: System>Preferences>ColorSync* Profiles
- Macintosh OS, with Colorsync 2.5 or higher: System>ColorSync* Profiles
- Windows 95, Windows 98: Windows>System>Color
- Windows NT4.x: Winnt>System32>Color

If a *ROMM RGB* ICC profile is not present, it is necessary to enter the *ROMM RGB* parameters via the RGB Setup dialog, as follows:

- Set Gamma to: 1.80
- Set White Point to: 5000 K (D50)
- Set custom *x-y* primaries for Red, Green, and Blue to:

Color	*x*	*y*
Red	0.7347	0.2653
Green	0.1596	0.8404
Blue	0.0366	0.00010

After these parameters are entered, select "*Save...*" to create an ICC profile, and store the profile in the default profiles directory. This allows plug-ins and other ICC-compatible applications to create and interpret *ROMM RGB* encoded imagery.

Note: saving the *ROMM RGB* profile is also useful if the RGB Working Space is changed from *ROMM RGB*. In this case, *ROMM RGB* can be re-established as the RGB Working

Space by choosing "*Load...*" from RGB Setup dialog box, and selecting the *ROMM RGB* profile.

Display Using Monitor Compensation **must be selected when working in *ROMM RGB*. An accurate Monitor Profile is necessary to establish the proper screen display of the *ROMM RGB* image.** Selecting this option converts the *ROMM RGB* image to Monitor RGB dynamically in the display path, using the following pair of profiles:

(1) *ROMM RGB* Profile - converts *ROMM RGB* to XYZ
(2) Monitor Profile – converts XYZ to monitor RGB.

An accurate monitor profile is necessary to establish the proper screen display of the *ROMM RGB* image. Kodak's monitor profiling product, Kodak Colorflow ICC monitor profile builder, works with the Xrite DTP92 monitor colorimeter to build an objective, instrument-based monitor profile for Macintosh and Windows platforms. Other ICC vendors have similar products. Refer to the user guide for techniques to build the best possible monitor profile.

Activating a monitor profile on the Macintosh

The monitor profile is established in the Colorsync Control Panel. Verify this by reading the profile description in the Control Panel, and ensuring that the same text string displays next to the "Display using Monitor Compensation" clickbox. If Photoshop software is running, it is not necessary to quit the application and re-launch to recognize the new Control Panel selection. The new selection is honored by the RGB Setup menu.

Please contact Kodak's Colorflow technical support center for more information about activating monitor profiles that have been tuned in Colorflow profile editor.

Activating a monitor profile on Windows 95

With the Kodak Colorflow ICC monitor profile builder, the application offers an option to set the monitor profile builder profile as the Photoshop 5 software default.

Alternatively, the monitor profile can be designated using the Adobe Gamma control panel. (*Note: This procedure must be used for OEM or default monitor profiles.*)

- Choose the *Control Panel* version of the program (the other version is a step-by-step visual calibration).
- Select the monitor profile and choose OK. A message appears: "Do you want to save changes to profile xxxxx". To get the profile to appear in the RGB Setup menu in Photoshop software V5.0, the answer has to be "yes."

(Note: Among the changes made are that the Copyright becomes Adobe Systems Inc., and any LUTs and multi-point TRCs are reduced to a single value TRC. This procedure can lose certain profile characteristics for custom-tuned monitor profiles.) Please contact Kodak's Colorflow technical support center for more

information about activating monitor profiles that have been tuned in Colorflow profile editor.

Activating a monitor profile on Windows 98

For Win98, first install the new monitor profile into ICM. This is done using the Display Control Panel. Use the Settings menu in that Control Panel and click on "Advanced...." to bring up a series of tabs that include a ColorManagement selection. Within here, a user can add monitor profiles to be associated with that card, and also identify a default profile. A profile needs to be on this list before Adobe Gamma will save it as a choice as the system monitor.

Once the system monitor profile is defined by one of the means above, the RGB Setup menu in Photoshop software will show this monitor profile as the monitor used to display through if the "Display with Monitor Compensation" is checked. Note that the profile description is used to identify the profile, so care should be taken to name the internal description with a suitable string.

Any editing done to the profile in Colorflow profile editor will be compromised by loading into Adobe Gamma as it will be changed to a single value. Please contact Kodak's Colorflow technical support center for more information about activating monitor profiles that have been tuned in Colorflow profile editor.

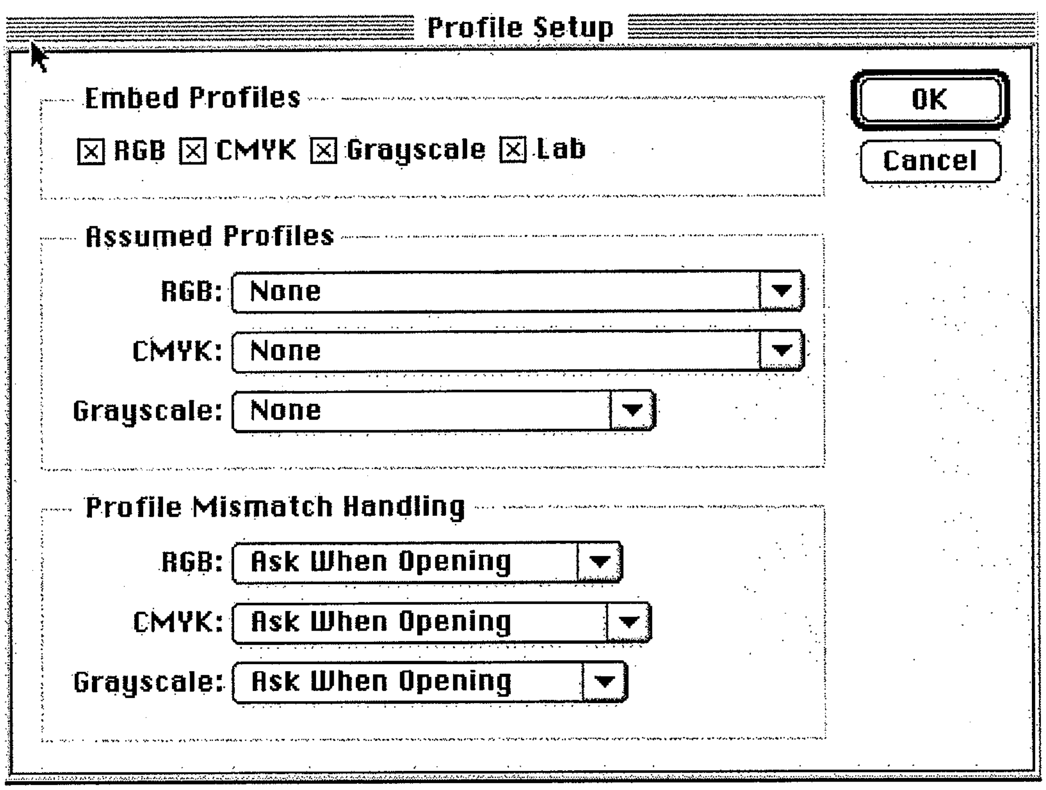

Fig. E2. Dialog box for *File>Color Preferences>Profile Setup* Menu option.

Saving ROMM RGB Images with a Profile Tag

To enable the embedding of RGB profiles in images, choose the "*File>Color Preferences>Profile Setup*" menu option. and select the settings shown in Fig. E2. RGB images must be tagged with the RGB Working Space profile to set up correct use upon re-open. Working in *ROMM RGB*, and tagging with the *ROMM RGB* profile, sets up the most flexible re-use in the future.

Note: profile tagging also allows use of the ICC output conversion process available in applications such as Page Layout, OPI Server, and PS RIP. This is more flexible than converting to an output-specific color space at the capture stage or inside Photoshop software.

Verifying the ROMM RGB Working Space

The following procedure can be used to verify that the *ROMM RGB* Working Space is being used correctly.

• Set the Profile Mismatch handling, in "*File>Color Settings>Profile Setup*" as show in Fig. E2. Setting the Mismatch handling to "*Ask When Opening*" will cause the *Open* command to pause and query the user when the image is tagged differently than the current Working Space.

• For example, open the *Bottles* image that is installed with Adobe V5.0 software, in the *Photoshop application folder>Goodies>Samples*. The *Bottles* image was tagged as *sRGB*. When the *Open* command checks the Working Space and finds *ROMM RGB* (something other than *sRGB*), the user is presented with the following dialog:

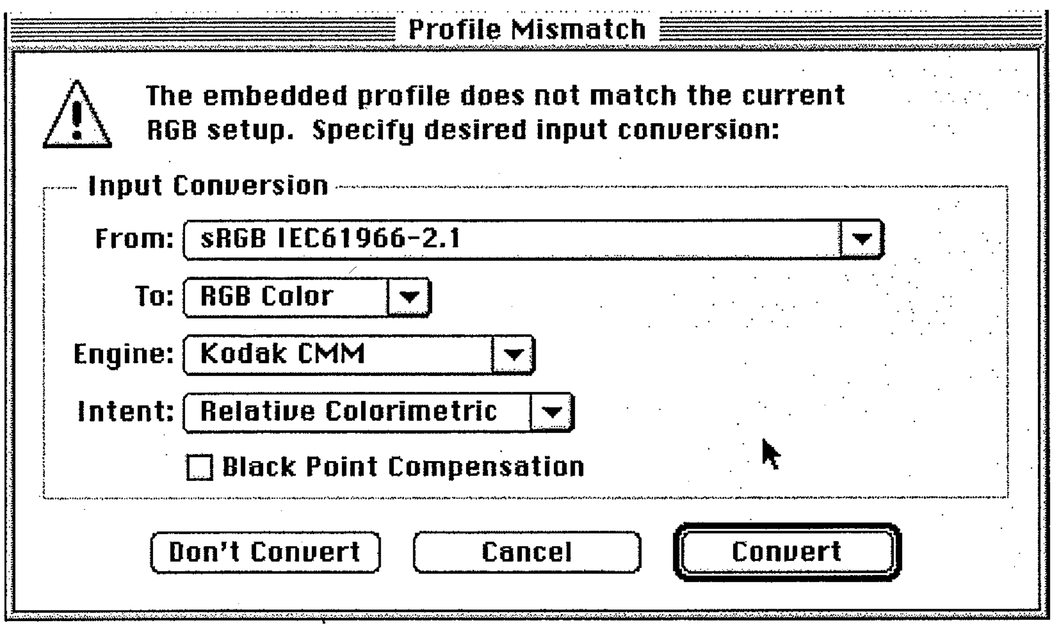

Fig. E3. *Profile Mismatch* Dialog Box.

• *Convert* is the default option and would be the usual selection in order to bring images from various sources into the common RGB Working Space, *ROMM RGB* in this example. (Although Adobe attempted to create a bullet-proof user interface, it is *possible* to work around the Adobe conventions, and either convert improperly or improperly not convert.) Go ahead and select *Convert.*

• *Save* the image as *Bottles.ROMM.* The profile is now tagged to the image.

• *Open* the *Bottles.ROMM* image once more. Now, there should be no *Profile Mismatch* message.

• *Open* the original *Bottles* image again. This time, answer "*Don't Convert*" for testing purposes. The image will contain sRGB data but will display as if it is *ROMM RGB*, so the image will appear over-saturated. Open the *RGB Setup* dialog, and turn off "*Display using Monitor Compensation*" temporarily. The image will appear less saturated (closer to proper display, since sRGB is a monitor definition). Close the dialog.

• Select the *Bottles.ROMM* image. The image will look desaturated relative to the *sRGB* image when "*Display using Monitor Compensation*" is turned OFF.

• Turn on "*Display using Monitor Compensation*" to display the image properly. Notice that the original *Bottles* image is now over-saturated relative to the correctly displayed *Bottles.ROMM* image.

• Close the *Bottles* image without saving it. (If it were saved, the *ROMM RGB* profile would be improperly tagged to the image in place of the *sRGB* tag.)

Troubleshooting Tips:

• If an image looks over-saturated on screen, then it's possible that a monitor-like RGB image was not converted to *ROMM RGB* upon open.

• If an image looks desaturated on screen then "*Display using Monitor Compensation*" might be turned OFF (it should be ON when using *ROMM RGB* as the Working Space).

• If an image looks desaturated on output then the *ROMM RGB* image might not have been converted to the output-specific color space (either within the Photoshop software or via an ICC-aware page layout or output system).

Opening Images and Converting to ROMM RGB *Working Space*

• PHOTO CD Open File Format Plugin

The Kodak ICC PHOTO CD Open file format plug-in is ICC-compatible. The Source is a PHOTO CD input profile, while the destination can be LAB, CMYK, monitor RGB, or output RGB.

Direct ICC conversion to a destination device color space is still available and useful within Adobe V5.0 software. However, using the RGB Working Space as a Destination profile is preferred. The procedure is as follows:

(1) If you don't already have a *ROMM RGB* ICC profile, create an ICC profile by selecting *Save..* from the *RGB Setup* dialog box.
(2) In the Open dialog, select the PHOTO CD input profile as Source profile (as usual). Select the ROMM RGB working space ICC profile as destination.
(3) Edit the image if needed
(4) Save the image to disk (ROMM RGB Working Space profile is embedded).

• Use of Non-ICC Acquire Modules

Input devices such as Kodak digital cameras and film scanners ship with Acquire plug-ins for the Adobe Photoshop software. These plug-ins are compatible with Adobe V5.0 software, even though they are not ICC-aware. There are a few user techniques that will aid the transition to Photoshop V5.0 software.

The most effective procedure is to convert from the input RGB to the RGB Working Space upon *Open*, by selecting *Image>Mode> Profile to Profile*. Select the custom input profile as the *Source*, and select the RGB Working Space profile as the *Destination*. (It is possible to build an *Action* that can be triggered at the touch of a function key to call the appropriate Action for the given source device.)

An alternative method is to set the custom input profile as the *Assumed Profile* for RGB images. This is convenient because the *Profile Setup* dialog can be set to apply the assumed profile upon open, in cases where the image is not already tagged. With this method, the conversion also utilizes the custom input profile as *Source*, and the RGB Working Space as *Destination*. However, if an image from another source (such as a different scanner, or digital camera) is opened, this image will be (incorrectly) converted. In summary, this approach is fine for single-source workstations, but is not recommended for general use.

• Opening Legacy Files

If an RGB image is "origin unknown", the normal procedure is to determine whether it came from a PC or Macintosh platform if possible. If it came from a PC, it is usually reasonable to convert from *sRGB* to the *ROMM RGB* Working Space. If it came from a Macintosh, it is reasonable to convert from *Colormatch* to the *ROMM RGB* Working Space.

If an image was originally stored in a monitor RGB space such as *Colormatch*, there will generally be some saturated colors that were clipped or compressed into the original monitor gamut. Therefore, this method should be considered to be "best efforts" only and is not necessarily optimal. The good news is that nothing will be lost by interchanging in and out of *ROMM RGB* during subsequent conversions.

Legacy CMYK files can also be re-expressed in alternate color spaces if an output profile is available that is representative of the site's output process. (Unfortunately, the result would include some gamut compression from having been stored in CMYK, but this approach can still be useful in many cases.) An *Action* can be established to *Open* a folder of CMYK images, convert from CMYK to *ROMM RGB*, and *Save* each image as a tagged *ROMM RGB* Tiff file.

Opening ROMM RGB Images

In order to exchange image files properly among workstations, all should be set up with the same profile preferences so that *ROMM RGB* images are not converted inadvertently. Specifically, *ROMM RGB* should be set as the Working Space, and profile embedding should be turned on for the saving of an RGB image.

This procedure avoids excessive conversions. If the tag equals the Working Space, no conversion is performed. Aside from converting legacy images to *ROMM RGB* upon *Open*, or converting images acquired from non-ICC devices, there is no reason to convert upon open. In particular, avoid exchanging images with a workstation that is not set to *ROMM RGB* because it will be needlessly converted there to a smaller gamut image – which defeats the purpose of adopting full gamut *ROMM RGB* editing.

ROMM RGB images can be created using an off-line process (e.g., KODAK COLORFLOW Image Server), or using another workstation with Photoshop software. The tagging protocol in Image Server V1.1 will conform to Adobe Photoshop V5.0 software, so that the Server can be used as a 100% compatible feeder to the Photoshop software.

Editing ROMM RGB Images

RGB mode in Adobe Photoshop V5.0 software offers 16-bit editing. This makes it possible to make a major tone move while in 16 bit mode with minimal artifacts. If the image is originally in an 8-bit image encoding, the 8-bit image can be mode changed to 16-bit in order to apply the Image adjust moves, then dropped back to 8-bit for final adjustments and output. The effect on the image data can be observed by comparing histograms of an image adjusted in 8-bit mode to that of an image adjusted in 16-bit mode.

Edits are possible while viewing the image in full gamut or with respect to output. While viewing and editing in full gamut, edits can be made without regard for the specific output process; this is equivalent to establishing the desired color appearance of the image (in ICC terms).

Alternatively, while viewing in Output Simulation, preferred reproduction characteristics can be imparted to an image that take into account the color gamut available for the chosen output process. Note: When storage and edit of the image in a device space is necessary, it is advisable to archive the device independent image prior to conversion.

ICC Soft Proof Filter

With Photoshop V5.0 software, accurate monitor viewing is finally in place for most image reproduction applications. RGB output simulations are the notable exception. The lack of support for viewing RGB simulations in the Photoshop V5.0 software suggests the use of Kodak ColorFlow ICC *soft proof* filters for certain applications.

Specifically, images that are in *ROMM RGB* but are intended for an RGB Output process (such as Durst Lambda), or images that have already been converted to an Output RGB color space, can be viewed properly with the help of the Soft Proof filter. (Note:

ICC Soft Proof is available for Macintosh only; a recent patch provides compatibility with OS 8.5.)

The editing of *ROMM RGB* images is possible in 8-bit or 16-bit depth. Although most filters are not available for use on 16 bit images, ICC Soft Proof is an exception. The Soft Proof filter is a toggle filter that operates on the contents of the graphics display buffer, so it remains active for 16-bit images that are displayed (although it must first be activated while an 8 bit image is displayed).

Printing ROMM RGB Images from Photoshop software

It would be ideal to maintain a single RGB file and convert the data while printing to different output devices. However, in Adobe Photoshop V5.0 software, you lose the flexibility of controlling rendering intent and color matching engine when the ICC conversion is invoked at print time.

Also, the printer color management checkbox doesn't control whether your printer uses color management or not, but only whether PS5 embeds color information describing your RGB work space in the stream of data sent to the print driver. It is unclear whether ICC profiles are being directly stored or whether they are being converted to CRDs, for use with PS Level 2 RIPS or higher. In either case, a non-compliant printer might show no conversion, or supersede it with an arbitrary "printer's default" conversion.

In summary: conversion at print time is still a risky business, but may be useful for closed-loop systems. Contact your printer vendor to establish the degree of PS5 and ICC/CRD compliance of a particular model.

A tried and true method is to convert the pixels to output device color space via a *Profile to Profile* command. Again, the use of a canned *Action* is suggested. In this case, it is especially important to avoid over-writing the *ROMM RGB* image with transient device data. For example:

(1) Select *Profile to Profile* to convert from *ROMM RGB* Working Space to XLS 8650 RGB, and print.
(2) Close the image without saving, to maintain the *ROMM RGB* image. Re-open the *ROMM RGB* image if additional output-specific images are needed.

Use of Tagged ROMM RGB images in other applications

If Adobe Photoshop V5.0 software is viewed in isolation, the tagging features are sufficient to allow proper saving and opening of *ROMM RGB* images. A standardized tagging mechanism allows a digital image to be transported to different applications and platforms without ambiguity about its origin. Additional application upgrades will emerge, that recognize and act upon the profile tag properly. Specifically, an ICC tagging compliant application will be able to use the tagged profile as *Source*, while supplying the *Destination* profile (monitor or output for example) to complete the reproduction chain.

In the next 6-12 months there will be very few applications other than the Photoshop software that are fully ICC-compliant, especially with the flavor of tagging introduced in Adobe Photoshop V5.0 software. Therefore, an alternative working space may be useful in conditions where a workstation downstream may not have Adobe Photoshop V5.0

software. If the ultimate user of the image data will NOT be using a color-managed application to convert the data to output-specific data, then the output will generally not be printed properly, and will typically be quite desaturated because of the encoding in the *ROMM RGB* Working Space. A Working Space such as Adobe RGB 98 may be more effective under this circumstance (note: V5.02 of the Photoshop software introduced Adobe RGB 98 as an additional Working Space). At minimum, take steps to ensure that the application is compatible with images created with a tagged RGB Working Space.

Bit Depth for ROMM RGB Working Space

An important consideration relative to the "editability" of an image in the ROMM RGB Working Space is the bit depth. RGB Working Spaces in the Photoshop software offer both 8-bit and 16-bit modes. (As discussed above, it is generally recommended that *ROMM12 RGB* images be converted to a 16-bit encoding when stored in a file that is to be read into Adobe Photoshop software.) Where possible, the 16-bit Working Space should be maintained in the Photoshop software for the manipulation of *ROMM16 RGB* images. In some cases it will be desirable to use the 16-bit Working Space option even for the manipulation of *ROMM8 RGB* images. This makes it possible to apply more aggressive image adjustments to an image with the minimal introduction of artifacts. The recommended approach for the most discerning color imaging professional is to make all major color appearance adjustments while in 16-bit *ROMM RGB* Working Space, then only drop back to 8-bit for any final fine tuning and specific "output preparation" adjustments.